NASA Technical Memorandum 102214 (Revision 1)

Vision Science and Technology at NASA: Results of a Workshop

February 1990

National Aeronautics and
Space Administration

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PREFACE

On November 30, 1988, about 50 scientists and engineers from various NASA centers convened at Ames Research Center to participate in a workshop on Vision Science and Technology (VST). The goals of the workshop were to

1. Refine the definition of Vision Science and Technology
2. Identify NASA needs in VST
3. Inventory NASA's expertise in relevant disciplines
4. Foster communication among NASA groups
5. Develop a strategy for NASA VST

During the next 3 days, workshop participants delivered presentations on a wide range of research projects dealing with basic vision science or application of this science to NASA missions. Participants also took part in discussions on how NASA could address future needs in this area. This document is a report on that workshop, and a white paper on the future of Vision Science and Technology in NASA. We wish to thank all those who contributed to the success of the meeting and to the completion of this report.

Andrew B. Watson

Jeffrey Mulligan

SUMMARY

This document attempts to provide a broad review of Vision Science and Technology within NASA. We have defined the subject, noted its applications in both NASA and the nation at large, and surveyed current NASA efforts in this area. We have noted the strengths and weaknesses of the NASA program, and have identified actions that might be taken to improve the quality and impact of the program.

This area has enormous potential. We are entering the visual age, in which visual communication is the global *lingua franca*, and robotic vision is the front end to an ever increasingly automated technology. At the intersection of computers, video, robotics, and imaging, a new science and technology is being born and it will have great consequences for NASA. To fully exploit this technological revolution, the agency should be prepared to participate actively and to assume a leadership role.

NASA TM-102214 (Revision 1) replaces an earlier document that was inadvertently printed without three abstracts.

EXECUTIVE SUMMARY

Through Vision Science and Technology (VST) researchers seek to understand the process of vision at the biological, physical, and mathematical levels, and to translate that understanding into practical advances in human factors, visual displays, image processing, and autonomous vision.

VST is an important element of many national initiatives in science and engineering, such as High-Definition Television, Human Genome Project, Superconducting Super Collider, and Strategic Defense Initiative, as well as in the efforts to revitalize American industry through increased automation.

VST is also an important element of many NASA programs and missions, such as Pathfinder, Space Station Freedom, National AeroSpace Plane, the Hypersonic Civilian Transport, Global Change Technology Initiative, and Aviation Safety. In these programs VST serves in the acquisition and analysis of scientific data, in the prediction of human performance, and in the provision of autonomous vision capabilities.

NASA currently supports a wide range of VST activities at a number of centers including Ames Research Center (ARC), Goddard Space Flight Center (GSFC), Lyndon B. Johnson Space Center (JSC), John C. Stennis Space Center (JSST), Jet Propulsion Laboratory (JPL), Langley Research Center (LaRC), and Lewis Research Center (LeRC). Much of this work has an excellent international reputation.

The NASA effort in VST is of high quality, but the level of effort is insufficient to meet the requirements of future NASA missions. The NASA program in VST could be strengthened sufficiently to meet these future challenges. Steps in this direction should include: explicitly acknowledging VST in planning and funding; enhancing the complement of in-house researchers; encouraging selective excellence in a small number of VST areas; establishing an in-house center of excellence in VST; encouraging collaboration with universities and among centers; and adopting a long-term emphasis on fundamental work in VST to support future applications.

VISION SCIENCE AND TECHNOLOGY

Vision Science and Technology describes a range of scientific and engineering areas that share a common goal of understanding visual processes in both human and machine. Visual processes extract information from imagery, both natural and synthetic. Visual processes can be examined and understood on many different levels, including biological, physical, and mathematical. Technical areas include fundamental research on human, biological, and artificial vision, engineering of artificial vision systems, image processing, visualization technology, and visual human factors. Vision Science draws on a number of diciplines, including

1. Psychology
2. Human factors
3. Neuroscience
4. Neural networks
5. Image processing
6. Computer science
7. Artificial intelligence
8. Communications engineering
9. Controls and guidance

Vision Technology comprises those practical devices, systems, and techniques derived from Vision Science. These technologies can be grouped in the following way:

1. Predictors of visual performance
2. Visual displays and interfaces
3. Image synthesis
4. Image management
5. Image analysis
6. Artificial vision

Specific examples of VST work under way within NASA are

1. Computational models of biological vision
2. Computer vision algorithms and applications
3. Image-processing algorithms and applications
4. Telescience
5. Remote sensing and analysis
6. Visualization and human interfaces
7. Neural networks for vision processing
8. Robust color analysis algorithms
9. Vision/sparse distributed memory for pattern recognition
10. Optimal computational architectures for vision
11. Assessment of human visual performance
12. Human-matched image coding
13. Helmet-mounted displays

14. Stereo displays
15. Fundamentals of Vision Science

Vision Science and Technology has experienced explosive growth in recent years. Computer vision is a burgeoning field, both because of its scientific challenges and because of its recognized importance in robotics and automation. There is also a torrent of information on the detailed neuroanatomy, neurophysiology, and psychophysics of biological vision, and these data are being exploited in computational models of biological vision as well as in artificial vision systems. Vision also figures prominently in neural network research, and in research on massively parallel computer architectures. Computer interfaces have become more graphic and "visual," and there is a heightened interest in visualization of scientific information. In all of these areas, Vision Science and Technology is coming to the fore as a coherent and critical discipline.

VST is, in the abstract, a powerful means of collecting and analyzing information about our physical surroundings. As such, it is natural that it will play an important role in an agency dedicated to research and discovery, on Earth and in space, by human and automated means. Vision Science and Technology is a vital element in NASA's overall research program, as documented below.

VST AND NATIONAL NEEDS

Vision Science and Technology plays a prominent role, not only in NASA, but also in the national scientific and engineering enterprise. The United States is contemplating or is currently engaged in a number of large scientific, engineering, and industrial projects that depend upon VST. The following sections provide some examples. Dollars indicated are budget requests or allocations, and are provided only to suggest the relative size of various programs.

High-Definition Television

There is now a strong sentiment in Congress and in industry that the United States should undertake a vigorous effort to develop the next-generation high-definition television system. Envisioned as a system using extensive digital processing to achieve at least two times the current television resolution, it will involve extensive research in VST areas such as visual human factors, image coding and compression, and image processing.

Earth Resources

National and international concern for the environment and for monitoring natural resources is creating an expanded need for Earth resource monitoring systems. Planning is under way within NASA for a Global Change Technology Initiative (see below), but this concern also extends to other agencies such as National Oceanic and Atmospheric Administration (NOAA), U. S. Geological Survey (USGS), Department of Transportation (DOT), Department of Defense (DOD), Environmental Protection Agency (EPA), Department of Agriculture, and private industry. Processing and visualization of Earth resource data is vital if the information is to be useful, and this involves extensive use of VST.

The Human Genome Project (M$100 FY90)

With the goal of mapping the entire human genetic code, this project is jointly managed by the National Institute of health (NIH) and the Department of Energy (DOE) and is anticipated to be one of the largest single scientific endeavors in the coming decades. The project can be accomplished only through extensive automation of tasks that are currently accomplished by human perception. It will therefore demand extensive use of automated visual pattern recognition and will require extensive advances in this area.

Superconducting Super Collider (M$160 FY90)

This high-energy physics project will also depend on automated pattern recognition systems for process monitoring and event detection. In addition, high-energy physics in general has come to depend upon advanced visualization techniques to render accessible massive data sets.

Industrial Revitalization

As we approach the 21st century, there is a need for revitalizing American industry. This will require greatly expanded automation of the manufacturing process, and this automation will involve extensive use of robotic vision.

Strategic Defense Initiative (M$5,591 FY90)

Initially envisioned as a space-based defensive shield against nuclear attack, this plan was dependent upon automated visual monitoring and identification of potential threats. The visual technologies called for were in fact well beyond what is currently possible. While the direction of this program is in some doubt, it seems certain that the national defense will move toward automated monitoring systems that depend on vision technology.

National Defense (M$315,000 FY90)

The military early recognized the potential of autonomous vision in enhancing the safety and effectiveness of military operations. The Defense Advanced Research Projects Agency (DARPA) has been the single largest source of funds for computer vision research in the last several decades, and continues to fund large applications of VST such as the Autonomous Land Vehicle(ALV). A recent "DOD Critical Technologies Plan" prepared for the Congressional Armed Services Committees, identified 22 specific technologies with extraordinary urgency or promise. Of these, five involve VST: machine intelligence/robotics, integrated optics, passive sensors, automatic target recognition, and data fusion.

Nuclear Power

Both generation of nuclear power and research on nuclear fission and fusion (M$349 FY90) employ remote and robotic vision for the monitoring of hazardous processes.

These examples illustrate the degree to which VST is a critical and growing component of our nation's scientific, economic, and military enterprise. Vision is an extraordinary system whereby humans absorb information about their world, in order to predict and control complex dynamic processes. As the technology matures, we are beginning to equip our machines, our organizations, and our nation with this powerful capability.

VST AND NASA NEEDS

Vision Science and Technology is a vital element in NASA's overall research program. It is a key element of virtually all future autonomous exploration activities, such as autonomous rovers, sample acquisition, and autonomous landing and docking. It has been and continues to be among the most critical elements of Space and Aviation Human Factors. And it is the leading edge in efforts to develop next-generation computational human factors for aerospace systems. Here we briefly document the critical role that is now or soon will be played by VST in a number of specific NASA programs.

Pathfinder

The Pathfinder program was designed to accelerate the development of critical technologies for advanced space missions. Of the 16 elements, 9 are paced by advances in VST. We examine the Pathfinder program in some detail, because it indicates the advanced technologies that NASA views as essential, and it illustrates how deeply VST is embedded in these technologies.

Planetary Rover

Autonomous exploration of planetary surfaces will require extensive advances in visual guidance and obstacle detection. Current accomplishments in autonomous land vehicles, such as the DARPA ALV project and the JPL rover work, fall far short of needs.

Sample Acquisition

Automomous identification of sites of geological interest, and analysis of collected samples, are essentially problems in visual pattern recognition. Both will use visible wavelength image data, as well as other methods.

Autonomous Rendezvous and Docking

Although these tasks may be achieved primarily through preplanned maneuvers and guidance telemetry, it seems likely that additional visual monitoring systems will be provided, to detect hazards and other unusual situations. The advantage of vision is that it can monitor the entire situation, not just those few signals deliberately provided.

In-Space Construction

Construction of large complex structures will require robots with sensing capability. The order of vision capability envisioned for these robots does not yet exist and will require extensive research.

Extravehicular Activity

Current activity focuses on high-pressure suits, but future work will necessarily turn to EVA information systems, displays, and controls. For example, design of helmet-mounted displays is highly dependent on principles derived from VST.

Human Performance

Design of the Human-Machine Interface has traditionally relied upon information about visual capacities of the user. This is becoming even more so with the advent of high-resolution, highly programmable, color displays, and with the approach of practical virtual environment displays. There is a general trend in display design toward a more graphic approach, and, consequently, a greater need for understanding human visual information processing.

Closed Environment Life Support

Closed life support systems will require augmented health monitoring to guard against toxic effects. Visual function testing is emerging as a promising technology for early detection of neural toxicology.

Autonomous Lander

Current technology is not adequate for fully autonomous landings. Vision technology is the leading candidate for guidance and hazard detection. Work on this application is currently under way within NASA.

Fault-Tolerant Systems

This element is concerned with photonic processing in terrain-analysis problems. Elements of VST such as image processing, pattern recognition, and parallel computation are fundamental.

Global Change

The Ride Report to the NASA Administrator on the future of the space program proposed a "Mission to Planet Earth," a concerted effort to study global change. In addition, national and international concern for the environment and for the monitoring of natural resources is creating an expanded need for Earth resource monitoring systems. Planning is under way within NASA for a Global Change Technology Initiative to augment the technologies that are critical to Earth observation. These technologies have been categorized as observation, information, and operation. The first two involve sensors and the processing, integration, and visualization of sensor data, and in all of these activities, VST plays an important role.

Space Station Freedom

Space Station Freedom (M$2,050 FY90) will require many of the technologies identified under Pathfinder, but it also has its own special challenges. Viewed in large measure as a site for extraterrestrial research, it will be the first large-scale effort toward *telescience*. The capability to conduct science at a distance is absolutely dependent on the ability to monitor events and either convey information visually to remote observers or automatically recognize critical events. As such, it will require extensive means for image capture, processing, storage, transmission, and display, and possibly for some autonomous vision.

The image demands of telescience, coupled with operational and informational needs of station occupants and those on the ground, create the need for general *image management* capabilities. The technology needs here are in areas such as image coding and compression, and image display.

Finally, the human crew must be augmented by automatic visual monitoring of station and environment. This is an instance of robotic vision, which may be more extensively used in later evolution of the station.

National AeroSpace Plane

National AeroSpace Plane (M$556 FY90), a joint effort of NASA and the U. S. Air Force to develop a hypersonic spacecraft that could take off and land like a conventional aircraft, will require remote viewing systems because of cockpit location and surface angles. It may also require autonomous vision systems to assist in guidance, deployment, and docking.

Aviation Safety

Aviation safety is an important element in NASA's goals and objectives. VST contributes to this element in two important ways. The first is in predicting human visual performance in guiding the craft, monitoring the outside world, and extracting information from displays. The second contribution is toward the design of cockpit displays, and more generally, toward crewstation design. This latter contribution is of ever greater importance as a revolution takes place in cockpit displays, in the form of color, CRT displays, multifunction displays, and advanced visualization techniques such as graphic flight directors and displays of air traffic.

Base Research and Technology

The preceding paragraphs describe large programs directed at specific technical or mission objectives. Beyond these, the base NASA research and technology program contains major components that involve VST. Examples in the Office of Aeronautics and Space Technology (OAST) are research in computer science and artificial intelligence, especially with respect to image processing, image analysis, and computer vision, and human factors, especially with respect to visual sensitivity, visual information processing, and visual displays. In the Office of Space Science and Applications (OSSA), examples are research on visual-vestibular interactions, and effects on vision of long-duration spaceflight.

The key technical areas are

1. Information display (display design, information formatting)
2. Image coding (image compression, storage, transmission)
3. Image analysis (scientific analysis, computer vision)
4. Human vision (data, models, guidelines)
5. Image synthesis (visualization, graphics, simulation)

NASA RESEARCH CENTERS

The material presented at the workshop, and other sources, demonstrate considerable expertise in VST at a number of NASA research centers. In this section we provide a brief survey of these centers. This survey is not exhaustive, and we apologize for ommisions.

Ames Research Center

Ames Research Center has VST activity under way in several areas. Codes FS and FL are collaborating on computer vision techniques for autonomous guidance of both the rotorcraft and the Mars lander. Code FL has a substantial group working on human and biological vision and its relation to image processing, display design, and computer vision. This group has extensive collaborations with vision scientists at Stanford, Berkeley, University of California, Irvine, University of California, Santa Cruz, and SRI (Menlo Park and Sarnoff). The Research Institute for Advanced Computer Science (RIACS), situated at Ames, is engaged in collaborative work with code FL on visual recognition and neural networks. Code RI is initiating a program in photonics research, including optical processors for visual recognition. Code RI also hopes to use vision technology for remote sample acquisition and analysis. Ames (code FL) has also played a leading role in technology utilization projects to use image processing in visual prosthetics.

Principal researchers include

Albert Ahumada, ARC-FL
Victor Cheng, ARC-FS
Mal Cohen, ARC-SL
Dallas Denery, ARC-FS
Steve Ellis, ARC-FL
Scott Fisher, ARC-FL
Mary Kaiser, ARC-FL
James Larimer, ARC-FL
Mike McGreevy, ARC-FL
Jeffrey Mulligan, ARC-FL
Ellen Ochoa, ARC-RI
Don Rosenthal, ARC-RI
Bonavar Sridhar, ARC-FS
Andrew Watson, ARC-FL
John Perrone, Stanford
Mike Raugh, RIACS
Lee Stone, FL-NRC
Matt Valeton, FL-NRC
Brian Wandell, Stanford

Goddard Space Flight Center

Goddard has recently established a Center for Excellence for Space Data and Information Sciences that may be involved in image analysis research.

Principal researchers include

J. Gualtieri, GSFC-RRA
M. Manohar, GSFC
Milt Halem, GSFC-Space Data and Computing

Jet Propulsion Laboratory

Jet Propulsion Laboratory has a substantial program of research in vision for robotics, which emphasizes technology for autonomous space operations. An example is work on stereo vision for autonomous rovers. JPL also has several experts on human and biological vision. This work has contributed to both robotics and human interface design, as well as prostheses for low vision.

JPL also has a section devoted to Image Processing Applications and Development, which has produced the SPAM package.

Other imaging science and technology is conducted in Section 34, which deals with the HIRIS infrared imaging system among other things.

Principal researchers include

Brian Wilcox, JPL
Donald Genery, JPL
Richard Anderson, JPL
Teri Lawton, JPL
Dan Diner, JPL
Ray J. Wall, JPL, Image Processing Applications and Development Section

Lyndon B. Johnson Space Center

Lyndon B. Johnson Space Center (JSC) has a number of research efforts concerned with vision. There is work in the areas of photonics, image processing, and human factors. The photonics work is in early stages, and will depend somewhat on NASA planning efforts now under way. The image processing work has led to the development of a general spatial remapper that has applications in guidance, machine vision, and prosthetics for low vision.

Principal researchers include

Richard D. Juday, JSC
Dave Loshin, Univ. of Houston, School of Optometry
Marianne Rudisill, JSC

John Stennis Space Center

John Stennis Space Center has expertise in image processing, traditionally applied to Earth resource issues, which they hope to apply as well to prostheses for low vision. They are currently collaborating with Johns Hopkins University on an image processing project.

The principal researcher is Doug Rickman, JSSC, Earth Resources Lab.

Langley Research Center

Langley Research Center has an active and widely recognized program that concentrates on issues of image acquisition, processing, and display. The emphasis of this program is on the development of focal-plane processing techniques and technologies to effectively combine image gathering with coding. They have extensive collaborations with Odetics, Inc., Microtronics, Inc., and University of California, Irvine. A notable product of this collaboration is the development of the Intensity Dependent Spread (IDS) model of retinal processing in a commercially available hardware implementation for image-processing systems, and in a neural network implementation that combines photon detection with asynchronous parallel processing.

Principal researchers include

Friedrich O. Huck, LaRC, Information Systems Division
Rachel Alter-Gartenberg, Old Dominion University
Tom Cornsweet, University of California, Irvine
Darryl D. Coon, Microtronics Associates, Inc.
Carl L. Fales, LaRC, Information Systems Division
Daniel J. Jobson, LaRC, Information Systems Division
Sarah John, Science and Technology Corp.
Eleanor Kurrasch, Odetics Inc.
Ramkumar Naranswamy, Science and Technology Corp.
George B. Westrom, Odetics Inc.

Lewis Research Center

A major focus of Lewis Research Center in vision and imaging is HHVT (High-Resolution High-Frame Rate Video Technology). The goal of this program is to assess needs and develop technology for video monitoring of microgravity experiments. It is expected that results will transfer to more general telescience applications. Major activity to date has concentrated on designing the imaging system, evaluating user requirements, and developing data compression techniques for onboard archiving and data transmission.

Image data compression techniques are also being developed to support lunar and planetary exploration missions to reduce communications channel bandwidth requirements for transmission of high-resolution images.

Principal researchers include

Robert Butcher, LeRC
Mike Lewis, LeRC
Marlene Metzinger, LeRC
Mary Jo Shalkhauser, Lerc
William Thompson, LeRC
Wayne White, LeRC
John Zuzek, LeRC
William Hartz, Analex
Khalid Sayood, U. Nebraska-Lincoln

STATUS OF NASA VST

To determine a future direction for NASA VST it is important to understand where we are now. In the previous section we described specific research projects now under way. Here we examine in a more general way the strengths and weaknesses of NASA's current VST program.

Strengths

Individuals and research– The most prominent strength of the existing NASA program is the quality of the individuals and their research. This is a strong base on which to build. A more detailed survey of NASA activities is given elsewhere in this report, but here we note that in a number of key areas, such as image processing, computational models of human and biological vision, motion processing, stereo, autonomous guidance, image coding and compression, and advanced visual displays, there exists a core of knowledge, achievement, and excellence. The quality of these efforts is objectively verified by numbers of journal publications and invited conference presentations.

Program attractiveness– Another strength that NASA brings to this challenge is its attractiveness, relative to industry and military programs, to talented researchers. While salaries and working conditions make it difficult to attract and retain the best people, particularly at the senior levels, many individuals are willing to sacrifice in order to work on "the final frontier." NASA has always prided itself on exploring technologies that are at the forefront of what is possible. Elsewhere, we have shown that VST permeates much advanced research. VST is, in addition, one of the more high-profile, glamorous facets of industrial and academic research and development. These facts recommend it as a suitable investment of NASA resources.

The center laboratories offer researchers an environment well-suited to support leading-edge research in many fields. The proximity of scientists and engineers working in related fields such as biology, computer science, and numerical analysis foster an atmosphere similar to that of leading research universities. The application-specific goals, a number of which have been enumerated above, bring excitement and energy to the endeavor. NASA scientists and engineers are in a unique position to bridge efforts in basic and applied research. This contributes significantly to the agency's ability to mount high-quality programs in VST.

Facilities– Advanced computational resources, such as powerful graphics workstations, image-processing systems, supercomputers, and parallel computers, are essential to VST, and NASA excels in this regard. NASA also has a number of specialized facilities, such as the Vision Laboratory at Ames Research Center, and image processing labs at JPL, Goddard and JSSC, and robotics lab at JPL, that contain unique resources.

Weaknesses

Lack of identity– With few exceptions, current NASA VST research projects are carried out under the umbrella of other programs, rather than supported as VST *per se*. The result is that researchers are frequently diverted to satisfy the explicit demands of the umbrella program. This is inefficient, and serves neither program well. VST will be pursued most effectively and enthusiastically when it is pursued single-mindedly.

Short-term emphasis– Another problem that must be acknowledged is the short-term orientation of many of NASA's research programs. Despite its mandate to pursue "long-lead, high-risk" research, NASA has difficulty in mustering the political and economic courage to support such programs. While VST may provide a number of near-term payoffs, it is a rich and difficult area that demands considerable long-term research investment. Perhaps the clearest example is in computer vision, where extraordinary benefits are almost guaranteed, but where current technology is crude, laborious, and ineffective.

Small numbers– Despite the magnitude of the vision problems that confront the agency, as described above, there is remarkably little in-house expertise. The agency has committed large sums of money to university research programs to assure that the base research and technology will be there when it is needed. But it should be evident that without in-house knowledge, the agency can neither adequateley select and monitor extramural research, nor will it be able to apply that research to NASA missions. It is clear that NASA cannot be effective in this area without additional investment in its in-house capability.

Connections– As Dr. Fletcher has noted, "NASA will never have enough money to do all the things it wants to do." It must leverage developments that occur in the industry, academia, and other national labs. This is undoubtedly true of VST, in the sense that the challenge is so large it cannot reasonably be undertaken by NASA alone. But the exploitation of extramural research requires that NASA researchers establish and maintain connections with the larger VST community. They can do this only if they have a quality VST program that is recognized by the larger community. In short, external expertise cannot be exploited unless there is internal expertise.

FUTURE OF NASA VST

We have reviewed the role of VST in achieving national and NASA goals, and we have examined the strengths and weaknesses of the current NASA VST program. In the following section we attempt to provide some specific proposals that may serve to build a sound and effective VST program for the future.

Education and Advocacy

Perhaps the most important single step that can be taken is to acknowledge VST as a coherent discipline that is central to NASA's goals. This is a matter of education and advocacy. It is important that those responsible for planning the direction of NASA programs understand the term VST, and that it become as familiar as "propulsion," "structures," "communications," or "artificial intelligence." This educational process is largely the responsibility of the VST community within NASA, and this document is a first step.

VST Program Support

The second step is to provide explicit program funding for VST. NASA Headquarters (HQ) should identify, hopefully with the aid of this document, research areas that fall within the purview for this funding program. A PASO should be generated, and centers should be invited to submit Research and Technology Objectives and Plans (RTOPs) to this program.

Research Planning

More consideration must be given to VST in planning specific science and technology research programs. Pathfinder is an example of a program in which VST needs are demonstrably great, but are not adequately dealt with.

Long-Term Emphasis

As noted previously, NASA efforts are hampered by a demand for short-term results and applications. HQ should have the political and economic courage, and the wisdom, to regard VST as a long-term research program. It is relatively inexpensive, and the potential benefits are very large, but we cannot expect excellence in the NASA program unless we invest for the future.

Quality

Too often NASA programs are judged on how much they produce, in terms of demonstrations, viewgraphs, and other superficial creations, or in terms of how directly they impact an immediate NASA need. This area, we submit, is one which should be judged in large part in terms of simple quality. Since much of it is long-term research, the surest criterion of ultimate benefit is excellence, judged by the conventional criteria of scientific research. HQ can monitor and reward excellence by noting refereed publications, invited presentations, memberships on distinguished committees, collaborations with eminent scientists, and the like. Quality is also encouraged by greater interaction of NASA personnel with each other and with the larger scientific/engineering community (see below).

Selective Excellence

NASA should foster excellence in a small set of research areas in which it can make a significant contribution. These areas should be chosen with respect to relevance to NASA goals and to the existing expertise of NASA groups, and to their long-term scientific and technology promise. Although it is hazardous to offer specifics, the following are candidates:

1. Image processing (Earth resource imagery, astronomy, image management)
2. Computational models of human and biological vision
3. Motion processing
4. Stereo processing
5. Autonomous visual guidance and hazard avoidance
6. Image coding and compression
7. Advanced visual displays
8. Visual human factors
9. Neural networks for visual processing
10. Human factors for visualization

Center of Excellence

HQ should consider, within the next decade, establishment of a Center of Excellence in VST. The center should capitalize on existing expertise at the research centers, and should be established in collaboration with a major university. The center should take advantage of existing NASA supercomputer resources. The center could perhaps be jointly funded by NASA, DOD, and industry.

Extramural Collaboration

To leverage NASA's internal research, strong collaborations with industrial and academic labs should be strongly encouraged. University research supported in this way is much more effective than grants that are merely "monitored." Specifically, this means that intramural funding should be sufficient to allow research groups at the individual centers to fund collaborative activities.

Intracenter Collaboration

Headquarters and individual centers should encourage collaboration and communication among the various centers. There are several mechanisms for accomplishing this

1. an annual intercenter workshop, such as those held at Ames in November 1988, and at Langley in May 1989
2. a common source of HQ funding for VST
3. a single program review for all VST research activities

We have already begun to develop a directory of individuals involved in NASA VST (see Appendix). We hope that this will be useful in planning and collaboration.

ABSTRACTS

The following are abstracts of presentations given at the Vision Science and Technology Workshop held at Ames Research Center, November 1988.

N90-22217

Sampling and Noise in Vision Networks

Albert J. Ahumada, Jr.

NASA Ames Research Center

This research is part of the Human Interface Research Branch-Vision Group's program to develop computable models of biological solutions to general vision system problems. Two problem areas are addressed: (1) effects of discrete sampling by receptors and (2) effects of visual system noise.

I. Image sampling

This research program originated as a collaboration with J. Yellott of UC Irvine on the question of why aliases are not seen in our normal vision as they are in images from other sampled systems. It has developed into a collaborative program with Yellott on the consequences of image sampling with the constrained sampling array disorder found in the retina.

A. Retinal cone arrangement models (Ahumada and Poirson, 1987). A hard disk packing algorithm with random variation in disk diameter can generate sampling arrays with the same sampling properties as the primate central fovea. 2. Peripheral cone positions (Yellott, 1983). The sampling properties of the peripheral cones are well represented by those of a Poisson hard disk process. 3. Red-green cone arrangement (Ahumada, 1987a). Simulated annealing allows models for the arrangement of the red and green cones to vary in disorder up to the maximum amount of order allowed by the cone array.

B. Receptor position learning models. Learning mechanisms can copy the detailed arrangement of receptor positions to higher levels of the visual system. 1. Weight adjustment models (Ahumada and Yellott, 1988a). Kohonen-like competitive learning models can construct topologically correct maps. 2. Position adjustment (Ahumada and Yellott, 1988b). Error-correcting position adjustment can generate maps with exact local position information and variable global magnification.

C. Interpolation network learning models. Interpolation of the sampled image allows further processing to ignore the details of the sampling. 1. Chen-Allenbach interpolation (Yellott, 1988). A generalization of their least squares interpolation works with both irregular spacing and variable density. 2. Network learning (Ahumada and Yellott, 1988b). A network implementable gradient descent learning algorithm allows the required matrix inverting network to be learned by spontaneous activity and self-generated feedback. 3. Related computational methods. Related algorithms can provide very efficient inversion of sparse matrices. They are also useful for inverting image encoding transformations.

II. Visual system noise limiting signal detection.

This research has been a collaboration with A. Watson and K. Nielsen at Ames, B. Wandell at Stanford, and D. Pelli at Syracuse. Matrix methods of signal processing are applied to visual models.

A. Equivalent noise of linear models 1. Spatial noise (Ahumada and Watson, 1985) Low contrast detection and recognition models can be represented either by a single filter with white noise or by an equivalent image noise. 2. Temporal noise (Watson, 1988) This concept is extended to the continuous temporal domain to provide a rational definition of neuronal signal detectibility.

B. Equivalent spatial noise of a nonlinear model (Ahumada, 1987b) For high contrast signals, masking dominates which can be represented as nonlinear signal compression or as stimulus-induced visual system noise.

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N90-22218

Networks for Image Acquisition, Processing, and Display

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The human visual system comprises layers of networks which sample, process, and code images. Understanding these networks is a valuable means of understanding human vision and of designing autonomous vision systems based on network processing. Ames Research Center has an ongoing program to develop computational models of such networks.

The models predict human performance in detection of targets and in discrimination of displayed information. In addition, the models are artificial vision systems sharing properties with biological vision that has been tuned by evolution for high performance. Properties include variable density sampling, noise immunity, multi-resolution coding, and fault-tolerance. The research stresses analysis of noise in visual networks, including sampling, photon, and processing unit noises.

Specific accomplishments include:

- Models of sampling array growth with variable density and irregularity comparable to that of the retinal cone mosaic
- Noise models of networks with signal-dependent and independent noise
- Models of network connection development for preserving spatial registration and interpolation
- Multi-resolution encoding models based on hexagonal arrays (HOP transform)
- Mathematical procedures for simplifying analysis of large networks

This program has resulted in six papers published or in press during the last year. Portions of this work were done in collaboration with Stanford University.

N90-22219

Parallel Asynchronous Hardware Implementation of Image Processing Algorithms

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Research is being carried out on hardware for a new approach to focal plane processing. The hardware involves silicon injection mode devices. These devices provide a natural basis for parallel asynchronous focal plane image preprocessing. The simplicity and novel properties of the devices would permit an independent analog processing channel to be dedicated to every pixel. A laminar architecture built from arrays of the devices would form a two-dimensional (2-D) array processor with a 2-D array of inputs located directly behind a focal plane detector array. A 2-D image data stream would propagate in neuron-like asynchronous pulse-coded form through the laminar processor. No multiplexing, digitization, or serial processing would occur in the preprocessing stage. High performance is expected, based on pulse coding of input currents down to one picoampere with noise referred to input of about 10 femtoamperes. Approximately linear pulse coding has been observed for input currents ranging up to seven orders of magnitude. Low power requirements suggest utility in space and in conjunction with very large arrays. Very low dark current and multispectral capability are possible because of hardware compatibility with the cryogenic environment of high performance detector arrays.

The aforementioned hardware development effort is aimed at systems which would integrate image acquisition and image processing. Acquisition and processing would be performed concurrently as in natural vision systems. A key goal of the research will be hardware implementation of algorithms, such as the intensity dependent summation algorithm and pyramid processing structures, which are motivated by the operation of natural vision systems. Implementation of natural vision algorithms could benefit from the use of neuronlike information coding and the laminar, 2-D parallel, vision system type architecture. Besides providing a neural network framework for implementation of natural vision algorithms, a 2-D parallel approach could eliminate the serial bottleneck of conventional processing systems. Conversion to serial format would occur only after raw intensity data has been substantially processed. An interesting challenge arises from the fact that mathematical formulation of natural vision algorithms does not specify the means of implementation, so that hardware implementation poses additional questions involving vision science.

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N90-22220

Visions of Visualization Aids:
Design Philosophy and Experimental Results

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Aids for the visualization of high-dimensional scientific or other data must be designed. Simply casting multidimensional data into a two- or three-dimensional spatial metaphor does not guarantee that the presentation will provide insight or parsimonious description of the phenomena underlying the data. Indeed, the communication of the essential meaning of some multidimensional data may be obscured by presentation in a spatially distributed format.

Useful visualization is generally based on pre-existing theoretical beliefs concerning the underlying phenomena which guide selection and formatting of the plotted variables. Two examples from chaotic dynamics are used to illustrate how a visualization may be more than a pretty picture but rather an aid to insight.

Dynamic visual displays can help understand how simulation parameters change with time and conditions but purely visual analysis is dependent upon a subjective perceptual assessment of the display. The hope is that a viewer can see new phenomena in the map of the data space that the display provides. The presumption that simple visual inspection of the displays will provide insight into the simulation, and especially reveal new phenomena, however, assumes the displayed images will be visually comprehensible. This comprehensibility, however, depends upon the appropriateness of the selections of axes and the inherent dimensionality of the phenomena to be uncovered. More specificity, if the display is to be more illuminating than confusing, at least its dimensionality must match the dimensionality of the phenomena. Anyone who has ever seen a dynamic two-dimensional projection of an irregularly tumbling four-dimensional cube will quickly appreciate the thrust of this requirement.

Visualization tools are particular useful for understanding inherently three-dimensional databases such as those used by pilots or astronauts during aircraft or spacecraft maneuvers. Two examples of displays to aid spatial maneuvering will be described. The first, a perspective format for a commercial air traffic display, illustrates how geometric distortion may be introduced to insure that an operator can understand a depicted three-dimensional situation. The second, a display for planning small spacecraft maneuvers, illustrates how the complex counterintuitive character of orbital maneuvering may be made more tractable by removing higher-order nonlinear control dynamics, and allowing independent satisfaction of velocity and plume impingement constraints on orbital changes.

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N90-22221

Vision Science and Technology for Supervised Intelligent Space Robots

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We believe that robotic vision is required to provide the rich, real-time descriptions of the dynamic space environment necessary to enable the intelligent connection between machine perception and action needed for free-flying robots that do real work in space. We also believe that space in low Earth orbit offers simplicities of only a few objects with these being man-made, known, and of cooperative design.

The focus of our recent work in robotic vision for application in intelligent space robots such as EVA Retriever is in visual function, that is, how information about the space world is derived and then conveyed to cognition. The goal of this work in visual function is first to understand how the relevant structure of the surrounding world is evidenced by regularities among the pixels of images, then to understand how these regularities are mapped on the premises that form the primitive elements of cognition, and then to apply these understandings with the elements of visual processing (algorithms) and visual mechanism (machine organization) to intelligent space robot simulations and test beds. Since visual perception is the process of recognizing regularities in images that are known on the basis of a model of the world to be reliably related to causal structure in the environment (because perception attaches meaning to the link between a conception of the environment and the objective environment), our work involves understanding generic, generally applicable models of world structure (not merely objects) and how that structure evidences itself in images. Causal structure is of interest so as to be able to predict consequences, anticipate events, and plan actions so as to achieve goals.

Despite a focus on visual function, the majority of the resources expended to date have gone into implementation of visual processing and visual mechanism to meet test bed requirements for determining object holdsite grasping with dexterous hands and for free-flying navigation with obstacle avoidance. Our test bed includes laser range imagers as well as multiple visible and infrared video cameras.

N90-22222

Computation and Parallel Implementation for Early Vision

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The problem of early vision is to transform one or more retinal illuminance images—pixel arrays—to image representations built out of primitive visual features such as edges, regions, disparities, clusters, ... These transformed representations from the input to later vision stages that perform higher level vision tasks including matching and recognition. We have developed algorithms for: 1) edge finding in the scale space formulation; 2) correlation methods for computing matches between pairs of images; and 3) clustering of data by neural networks. These algorithms are formulated for parallel implementation of SIMD machines, such as the MPP (Massively Parallel Processor), a 128 × 128 array processor with 1024 bits of local memory per processor. For some cases we can show speedups of three orders of magnitude over serial implementations.

(1) Edge Detection in Scale Space [M. Manohar and J.A. Gualtieri, in preparation]

Edge focusing [Bergholm, PAMI-9, 726-741 (1987)] generalizes standard edge detection approaches by performing edge detection at a series of scales and tracks the edges from coarse to fine scales. We begin with the Canny edge detector [J. Canny, PAMI-8, 678-698 (1986)] which convolves the image, I, with the gradient of a Gaussian of size sigma to smooth the image and finds the direction and magnitude of the gradient of the image at each pixel. Non-maximum suppression then detects the edge pixels. We write E(I; sigma) to denote the binary image of pixels so found [an edge pixel is assigned the value 1 and all others are 0]. To this initial edge image we perform a "dilation," which generates a binary mask of pixels, D (E(I, sigma), t), that are within distance t of the already found edge pixels. We again apply the Canny edge detector, but now with a smaller sigma to obtain edges resolved to the smaller sigma, and only to those pixels in the mask D. Because Bergholm has proved that edges move at most 1 pixel if sigma changes by 0.5, no edges are lost. By repeating the dilation followed by edge detection until we reach a sigma of size 1 we obtain good edge localization. All computation is inherently local and it is straightforward to map the algorithm on the MPP.

(2) Correlation Methods for Computing Matching in Image Pairs [J.P. Strong, H.K. Ramapriyan, Second Symposium on Super Computers, Santa Barbara (1987)]

A generalization of the stereo problem is to compute local rotations and displacements for a pair of images—called the reference image and test image—that matches sub-regions in the image pairs. An application of this method is to obtain a vector flow field describing the motion of ice floes (the sub-regions) imaged by synthetic aperture radar from a spacecraft at different times. The algorithm contains an outer loop that steps through one-half-degree rotations, theta, of the test image relative to the reference image. For each rotation, the algorithm computes a global cross correlation of the reference image relative to the rotated test image as a function of translation in the horizontal and vertical directions of the test image. The cross correlation is then thresholded to select a set of displacements corresponding to the largest global matches in the image pairs. Next, for each such displacement the test image is shifted by that displacement to obtain a rough match of sub-regions in the image pairs. To find the actual sub-regions matched, a local cross correlation between a pair of small windows, say 11×11 (in a 512×512 image), in the reference and test images is computed for each pixel in the reference image over a search area of a few pixels in the horizontal and vertical directions. Marking the pixels at which this "local correlation" exceeds a threshold generates a mask defining the matching sub-regions in the reference and test images and further gives for each pixel in the sub-region in the reference image the total displacement (one part from the rotation plus global cross-correlation displacement and a smaller displacement from the local cross correlation) the matching pixel in the sub-region in the test image. While this algorithm is computationally intensive, it has been successfully mapped to the MPP and runs in times of the order of a few minutes.

(3) Clustering of Point Sets by Neural Networks [B. Kamgar-Parsi, J.A. Gualtieri, J.E. Devaney, and B. Kamgar-Parsi, Proc. of the Second Symposium on the Frontiers of Massively Parallel Computing, George Mason Univ. (1988)]

An important problem for early vision is to be able to partition N visual features, such as points in a two-dimensional space, into K clusters—in a way that those in a given cluster are more similar to each other than to the rest of the clusters. As there are approximately K**N/K! ways of partitioning the points among the K clusters, finding the best solution is beyond exhaustive search when N is large (say 128). This problem can be formulated as an optimization problem for which very good, but not necessarily optimal solutions can be found using a neural network. We have constructed a cost function to be minimized that is composed of a "syntax" term that enforces the constraint that each point must belong to only one cluster, and a "goodness of fit" term that measures the quality of the solution. Though the problem involves a discrete optimization, by embedding it in the continuous space of an analog network we are able to perform a downhill search on the cost function that is more purposeful and effective than a search in a discrete space. Solutions are generated by starting the network from many randomly selected initial states and then taking the best solution from the ensemble of solutions found. The network is simulated on the MPP where we use the massive parallelism not only in solving the differential equations that govern the evolution of the network, but also in starting the network from many initial states at once thus obtaining many solutions in one run. We obtain speedups of two to three orders of magnitude over serial implementations and further we obtain better quality solutions than conventional techniques such as K-means clustering.

We see the neural network approach as being important for early vision in that 1) the methods of "programming" neural networks described here can be generalized to other problems such as determining cluster shape, fitting more general features such as lines and parametric curves to visual data, and extending these results to higher dimensional spaces, and, 2) with the advent in the next few years of Analog VLSI devices, these algorithms can be straightforwardly mapped to silicon with potential speedups of up "nine orders of magnitude" over conventional serial implementations.

N90-22223

Intensity Dependent Spread Theory

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The Intensity Dependent Spread (IDS) procedure is an image-processing technique based on a model of the processing which occurs in the human visual system (1,2). IDS processing is relevant to many aspects of machine vision and image processing. For quantum limited images, it produces an ideal trade-off between spatial resolution and noise averaging, performs edge enhancement thus requiring only mean-crossing detection for the subsequent extraction of scene edges, and yields edge responses whose amplitudes are independent of scene illumination, depending only upon the ratio of the reflectance on the two sides of the edge. These properties suggest that the IDS process may provide significant band-width reduction while losing only minimal scene information when used as a preprocessor at or near the image plane.

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N90-22224

Image Gathering, Coding, and Processing: End-to-End Optimization for Efficient and Robust Acquisition of Visual Information

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We are concerned with the end-to-end performance of image gathering, coding, and processing. The applications range from high-resolution television to vision-based robotics, wherever the resolution, efficiency and robustness of visual information acquisition and processing are critical. For our presentation at this workshop, it is convenient to divide research activities into the following two overlapping areas:

1) The development of focal-plane processing techniques and technology to effectively combine image gathering with coding. The emphasis is on low-level vision processing akin to the retinal processing in human vision. Our approach includes the familiar Laplacian pyramid, the new intensity-dependent spatial summation, and parallel sensing/processing networks. Three-dimensional image gathering is attained by combining laser ranging with sensor-array imaging. This work is summarized in the following five abstracts by T. Cornsweet, G. Westrom, E. Kurrasch and R. Holben, R. Holben and G. Westrom, and D. Coon and A. Perera.

2) The rigorous extension of information theory and optimal filtering to visual information acquisition and processing. The goal is to provide a comprehensive methodology for quantitatively assessing the end-to-end performance of image gathering, coding, and processing. Information theory allows us to establish upper limits on the visual information which can be acquired within given constraints, and optimal filtering allows us to establish upper limits on the performance that can be attained for specific tasks, even if these tasks require adaptive or interactive processing. This work is summarized in the remainder of this abstract.

The performance of (digital) image-gathering systems is constrained by the spatial-frequency response of optical apertures, the sampling passband of photon-detection mechanisms, and the noise generated by photon detection and analog-to-digital conversion. Biophysical limitations have imposed similar constraints on natural vision. Visual information is inevitably lost in both image gathering and low-level vision by aliasing, blurring, and noise. It is therefore no longer permissible to assume sufficient sampling as Shannon and Wiener could do in their classical works, respectively, on communication theory and optimal filtering for time-varying signals. Nevertheless, the digital processing algorithms (for image restoration, edge enhancement, etc.) found in the currently prevailing literature assume sufficient sampling, whereas image-gathering systems are ordinarily designed to permit considerable insufficient sampling. This fundamental difference between assumption and reality has caused unnecessary limitations in the performance of digital image gathering, coding, and processing. It has also led to unreliable conclusions about the correct design of image-gathering systems for visual information processing (as opposed to image reconstruction without processing, e.g., commercial television) and about the actual performance of image-coding schemes for tasks which involve digital image processing.

Our analyses so far have shown that the combined process of image gathering and optimal processing can be treated as a communication channel if (and only if) the image-gathering degradations are correctly accounted for. Correctly restored images gain significantly in fidelity (similarity to target), resolution (minimum discernible detail), sharpness (contrast between large areas), and clarity (absence of visible artifacts). These improvements in visual quality are obtained solely by the correct end-to-end optimization without increase in either data transmission or processing. Similar improvements can also be made in the resolution and accuracy of edge detection. Furthermore, if we implement the edge enhancement with focal-plane processing by properly combining optical response with lateral inhibition, it is possible to reduce data processing and transmission requirements and to improve robustness to noise. These results have encouraged us to extend our analyses to various image-coding schemes and the associated image restoration and feature-extraction algorithms.

N90-22225

Hybrid Vision Activities at NASA Johnson Space Center

Richard D. Juday

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NASA's Johnson Space Center in Houston, Texas, is active in several aspects of hybrid image processing. (The term "hybrid image processing" refers to a system that combines digital and photonic processing.) Our major thrusts are autonomous space operations such as planetary landing, servicing, and rendezvous and docking. By processing images in non-Cartesian geometries to achieve shift invariance to canonical distortions, we use certain aspects of the human visual system for machine vision. That technology flow is bidirectional; we are investigating the possible utility of video-rate coordinate transformations for human low-vision patients. Man-in-the-loop teleoperations are also supported by the use of video-rate image-coordinate transformations, as we plan to use bandwidth compression tailored to the varying spatial acuity of the human operator.

Technological elements being developed in the program include upgraded spatial light modulators, real-time coordinate transformations in video imagery, synthetic filters that robustly allow estimation of object pose parameters, convolutionally blurred filters that have continuously selectable "invariance" to such image changes as magnification and rotation, and optimization of optical correlation done with spatial light modulators that have limited range and couple both phase and amplitude in their response.

Liaisons of varying degree of activity level and maturity exist between JSC and the Army (the Missile Command at the Redstone Arsenal—SLM and filter development, the Human Engineering Laboratory at the Aberdeen Proving Ground—video image compression for teleoperations), and the Air Force (RADC, Hanscom Field—exchanges relating to phase-mostly filter theory). JSC is promulgating a NASA participation in the DARPA/MICOM/RADC optical correlator development, to conform the results of that hardware development for use in space vision.

N90-22226

Human Motion Perception: Higher-Order Organization

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University of Virginia

This talk presents an overview of higher-order motion perception and organization. We argue that motion is sufficient to fully specify a number of environmental properties, including: depth order, three-dimensional form, object displacement, and dynamics. A grammar of motion perception is proposed; applications of this work for display design are discussed.

Goals of Research:

To define the competencies, limitations, and biases in human perception of motion events.

Application:

To design dynamic displays which exploit operators' competencies and compensate for limitations and biases.

What kinds of information can be specified via motion?

- Surface segregation
- Three-dimensional form
- Object displacement
- Dynamics

Surface Segregation (Depth Order Specification)

- Static depictions must rely on cues, conventions, or appeals to expectations: contrast, occlusion, familiarity, shading

- Motion, in and of itself, is sufficient to fully specify depth order (even if edge information is deleted)

Three-Dimensional Form

- An indefinite number of three-dimensional distal objects could produce a given two-dimensional pattern.
- Form specification through rotation resolves ambiguity (assuming rigid object): Kinetic Depth Effect.

• Perspective information (e.g., foreshortening of lines) not required; works with point-light display.

Object Displacement

• Motion of objects relative to observer virtually impossible to depict with static symbols and conventions.
• It is necessary to consider how the perceptual system parses object motion.

Dynamics

• Kinematics can specify underlying kinetics, at least to classes of solutions (e.g., relative masses of colliding objects).
• Observers demonstrate appreciations of dynamic properties even for events about which they hold erroneous beliefs.

Current Research

• Determine limits of perceptual competence (e.g., angular systems)
• Differentiate observers' ability to extract kinematic information vs. ability to perform dynamic analysis
• Develop taxonomy of event complexity (particle vs. extended body, dimensionality, dynamical feature analysis)

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N90-22227

Two-Dimensional Shape Recognition Using Sparse Distributed Memory

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We propose a method for recognizing two-dimensional shapes (hand-drawn characters, for example) with an associative memory. The methods consists of two stages: First, the image is preprocessed to extract tangents to the contour of the shape. Second, the set of tangents is converted to a long bit string for recognition with sparse distributed memory (SDM). [SDM provides a simple, massively parallel architecture for an associative memory. Long bit vectors (256-1000 bits, for example) serve as both data and addresses to the memory, and patterns are grouped or classified according to similarity in Hamming distance. See Kanerva (1988) for details on SDM, and Keeler (1988) for a comparison to Hopfield nets.]

At the moment, tangents are extracted in a simple manner by progressively blurring the image and then using a Canny-type edge detector (Canny, 1986) to find edges at each stage of blurring. This results in a grid of tangents, such as shown in Figure 1 for the letter A. While the technique used for obtaining the tangents is at present rather *ad hoc,* we plan to adopt an existing framework for extracting edge orientation information over a variety of resolutions, such as suggested by Watson (1987, 1983), Marr and Hildreth (1980), or Canny (1986).

The grid of tangent is converted to a long bit pattern by encoding the orientation at each point with three bits. The three-bit encodings for each orientation are chosen in such a way that the Hamming distance between code words is related to angular distance, as shown in Table 1. The encodings at all the grid points are then concatenated into a long bit pattern, as shown in Figure 2. This bit pattern then serves as a reference address and/or data word for SDM.

The main advantages of this approach are that 1) SDM is capable of searching among many stored patterns in parallel, 2) SDM corrects for noise in the address and data, and 3) the features obtained from the preprocessing stage are chosen and encoded in such a way that bit patterns corresponding to perceptually similar shapes (as judged by humans) are close to each other in Hamming distance. We are currently running simulations of this method on a SUN 3/60.

N90-22228

The Intensity Dependent Spread Model and Color Constancy

Ellie Kurrasch

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Odetics is investigating the use of the intensity dependent spread (IDS) model for determining color constancy. Object segmentation is performed effortlessly by the human visual systems, but creating computer vision that takes an image as input and performs object identification on the basis of color has some difficulties. The unknown aspects of the light illuminating a scene in space or anywhere can seriously interfere with the use of color for object identification. The color of an image depends not only on the physical characteristics of the object, but also on the wavelength composition of the incident illumination. IDS processing provides the extraction of edges and of reflectance changes across edges, independent of variations in scene illumination. IDS depends solely on the ratio of the reflectances on the two sides of the edge. We are in the process of using IDS to recover the reflectance image.

N90-22229

Filling in the Retinal Image

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The optics of the eye form an image on a surface at the back of the eyeball called the retina. The retina contains the photoreceptors that sample the image and convert it into a neural signal. The spacing of the photoreceptors in the retina is not uniform and varies with retinal locus. The central retinal field, called the macula, is densely packed with photoreceptors. The packing density falls off rapidly as a function of retinal eccentricity with respect to the macular region and there are regions in which there are no photoreceptors at all. The retinal regions without photoreceptors are called blind spots or scotomas.

The neural transformations which convert retinal image signals into percepts fills in the gaps and regularizes the inhomogeneities of the retinal photoreceptor sampling mosaic. The filling in mechanism is so powerful that we are generally not aware of our physiological blind spot, where the nerve head exits the eyeball, or other naturally occurring scotomas such as the central field loss that occurs during night vision. Individuals with pathological scotomas are also generally unaware of the field losses that result from the pathology.

The filling-in mechanism plays an important role in understanding visual performance. For example, a person with a peripheral field loss is usually unaware of the loss and subjectively believes that his or her vision is as good as ever, yet his or her performance in a task such as driving can be severely impaired.

The filling-in mechanism is not well understood. A systematic collaborative research program at the Ames Research Center and SRI in Menlo Park, California, has been designed to explore this mechanism. It has been known for some time that when an image boundary is stabilized on the retina the boundary is not perceived. Using image-stabilization techniques, we have been able to show that retinally local adaptation (the control of sensitivity) can be separated from more central neural effects which control the appearance of fields. In particular, we have shown that the perceived fields which are in fact different from the image on the retina due to filling-in control some aspects of performance and not others. We have linked these mechanisms to putative mechanisms of color coding and color constancy.

N90-22230

A3I Visibility Modeling Project

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The University of Pennsylvania

The Army-NASA Aircrew Aircraft Integration program is supporting a joint project to build a visibility computer-aided design (CAD) tool. The principal participants in the project are Dr. James Larimer of the Ames Research Center, Dr. Aries Arditi of the Research Department of the New York Association for the Blind, Dr. James Bergen of the SRI Sarnoff Research Laboratories, and Dr. Norman Badler of the University of Pennsylvania.

CAD has become an essential tool in modern engineering applications. CAD tools are used to create engineering drawings and to evaluate potential designs before they are physically realized. The visibility CAD tool will provide the design engineer with a tool to aid in the location and specification of windows, displays, and control in crewstations. In an aircraft cockpit the location of instruments and the emissive and reflective characteristics of the surfaces must be determined to assure adequate aircrew performance. For example, how big should letters be on a display to assure that they can always be read without error? How much contrast should the symbols have with the background? How bright should emissive displays be so that they will not be "washed out" by bright sunlight?

The visibility CAD tool will allow the designer to ask and answer many of these questions in the context of a three-dimensional graphical representation of the cockpit. The graphic representation of the cockpit is a geometrically valid model of the cockpit design. A graphic model of a pilot, called the pilot manikin, can be placed naturalistically in the cockpit model. The visibility tool has the capability of mapping the cockpit surfaces and other objects modeled in this graphic design space onto the simulated pilot's retinas for a given visual fixation. Moreover, the binocular retinal "footprint" can be mapped onto the environmental surfaces implied by the cockpit design and modeled objects in the graphic space. These capabilities and the sequential application of them permit the designer to estimate the required size and contrast of letters, numbers and symbols to be used by the instruments. Moreover, the system will permit the application of human visual processing models to predict the legibility of textual materials in the displays. Models of the ambient lighting and the adaptation state of the simulated pilot are being adapted to permit predictions of visibility and legibility over a large variety of conditions.

N90-22231

Motion Detection in Astronomical and Ice Floe Images

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Two approaches are presented for establishing correspondence between small areas in pairs of successive images for motion detection. The first one, based on local correlation, is used on a pair of successive Voyager images of the Jupiter which differ mainly in locally variable translations. This algorithm is implemented on a sequential machine (VAX 780) as well as the Massively Parallel Processor (MPP). In the case of the sequential algorithm, the pixel correspondence or match is computed on a sparse grid of points using nonoverlapping windows (typically 11 x 11) by local correlations over a predetermined search area. The displacement of the corresponding pixels in the two images is called the disparities to cubic surfaces. The disparities at points where the error between the computed values and the surface values exceeds a particular threshold are replaced by the surface values. A bilinear interpolation is then used to estimate disparities at all other pixels between the grid points. When this algorithm was applied at the *red spot* in the Jupiter image, the rotating velocity field of the storm was determined.

The computation required for this algorithm is proportional to the area of the image and is about one-half hour for a 128 × 128 image with local window of size 11 × 11 and search area of 11 × 11. The parallel implementation on the MPP is exactly same except that correspondences are established at every point rather than on a sparse grid of points. Thus this implementation needs no interpolation step. The results obtained in both cases are comparable for this image. However for images which are not smooth, the implementation on the MPP giving results at each pixel is more accurate. The time taken on the MPP is about 10 seconds.

The second method of motion detection is applicable to pairs of images in which corresponding areas can experience considerable translation as well as rotation. Ice floe images obtained from the synthetic aperture radar (SAR) instrument flown onboard the Seasat spacecraft belong to this class. The time interval between two successive images of a given region was as much as three days. During this period, large translations and rotations of ice floes can occur. Therefore, conventional local correlation techniques which perform searches in a small neighborhood to detect translated features have a very small chance of success. To account for large translations and rotations, it is necessary to perform large area searches in a three-dimensional space (two translational and one rotational). This makes conventional correlation techniques computationally intensive even on a high-speed parallel computer such as the MPP. A parallel algorithm has been developed and implemented on the MPP for locating corresponding objects based on their translationally and rotationally invariant features. The algorithm first approximates the edges in the images by polygons or sets of connected straight-line segments. Each such "edge structure" is then reduced to a "seed point." Associated with each seed point are the descriptions (lengths, orientations, and sequence numbers) of the lines constituting the corresponding edge structure. A parallel matching algorithm is used to match packed arrays of such descriptions to identify corresponding seed points in the two images. The matching algorithm is designed such that fragmentation and merging of ice floes are taken into account by accepting partial matches. The technique has been demonstrated to work on synthetic test patterns and real image pairs from Seasat in times ranging from 0.6 to 0.7 seconds for 128 × 128 images.

Passive Navigation Using Image Irradiance Tracking

P. K. A. Menon[1]

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Rotorcraft operating at low altitudes require navigational schemes for detecting terrain and obstacles. Due to the nature of the missions to be accomplished and available power onboard, a passive navigation scheme is desirable in this situation. This paper describes the development of a passive navigation scheme using optical image sequences and vehicle motion variables from an onboard inertial navigation scheme. This approach combines the geometric properties of perspective projection and a feedback irradiance tracking scheme at each pixel in the image to determine the range to various objects within the field-of-view. Derivation of the numerical algorithm and simulation results are given. Due to the feedback nature of the implementation, the computational scheme is robust. Other applications of the proposed approach include navigation for autonomous planetary rovers and telerobots.

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N90-22233

Factors Affecting the Perception of Transparent Motion

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It is possible to create a perception of transparency by combining patterns having different motions. Two particular combination rules, have specific interpretations in terms of physical phenomena: additive (specular reflection) and multiplicative (shadow illumination). Arbitrary combination rules applied to random patterns generate percepts in which the motions of the two patterns are visible, but have superimposed noise. It is also possible to combine the patterns (using an exclusive-OR rule) so that only noise is visible. Within a one-dimensional family of combination rules which include addition and multiplication, there is a range where smooth motions are seen with no superimposed noise; this range is centered about the additive combination. This result suggests that the motion system deals with a linear representation of luminance, and is consistent with the analysis of motion by linear sensors.

This research gives tentative validation the use in beam splitters (which combine images additively) in the construction of heads-up aviation displays. Further work is needed to determine if the superiority of additive combination generalizes to the case of full-color imagery (there are results in the literature suggesting that subtractive color mixture yields the best legibility of overlapping alphanumerics).

N90-22234

Photonic Processing at NASA Ames Research Center

Ellen Ochoa and Max Reid

NASA Ames Research Center

The Photonic Processing group is engaged in applied research on optical processors in support of the Ames vision to lead the development of autonomous intelligent systems. Optical processors, in conjunction with numeric and symbolic processors, are needed to provide the powerful processing capability that is required for many future agency missions. The research program emphasizes application of analog optical processing, where free-space propagation between components allows natural implementations of algorithms requiring a large degree of parallel computation. Special consideration is given in the Ames program to the integration of optical processors into larger, heterogeneous computational systems. Demonstration of the effective integration of optical processors within a broader knowledge-based system is essential to evaluate their potential for dependable operation in an autonomous environment such as space.

The Ames Photonics program is currently addressing several areas of interest. One of the efforts is to develop an optical correlator system with two programmable spatial light modulators (SLMs) to perform distortion invariant pattern recognition. Part of this work has been to develop a new type of filter to be placed in the spectral plane that uses information in the design procedure about the particular SLM on which it will be implemented. Laboratory work is aimed at the verification of this filter's performance. The SLM device used in our laboratory is an electronically-addressable magneto-optic array known as a SIGHT-MOD. An electronic controller for the SIGHT-MOD has been designed, built, and is currently being tested; the controller will be able to store 100 filters used for object recognition and rapidly address the device with a desired sequence of filters. This high-speed I/O capability is a key step in plans to integrate the optical processor with a knowledge-based system for image recognition and classification.

Another area of research is optical neural networks, also for use in distortion-invariant pattern recognition. Most promising of the models investigated are higher-order neural networks; to date, a small third-order net which distinguishes two objects regardless of size, position, or rotation has been demonstrated in software. The large number of interconnections needed in these architectures leads to consideration of optical implementations. Experimental work on developing an optical neural network will involve evaluating holographic implementations of weighted network connections, as well as testing optical or hybrid optical/electronic implementations of thresholding units to realize neuronic elements.

Optical matrix processors are being investigated for implementing neural net techniques to perform multispectral data analysis. The problem is to sort out three-dimensional (x,y,lambda) data and determine for every pixel in a scene all minerals present, amount of each, and estimate spectrum of unknown elements. This type of analysis is needed for site selection and sample analysis on planetary explorations as well as many types of astronomical and earth sensing data.

N90-22235

Sparse Distributed Memory Overview

Mike Raugh

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One of NASA's grand challenges is to build autonomous machines and systems that are capable of learning to perform tasks too tedious, or in places too remote and too hostile, for humans. The goal of the Learning Systems Division of RIACS is to find new approaches to autonomous systems based upon sound mathematical and engineering principles and the need to know how information processing is organized in animals, and to test the applicability of these new approaches to the grand challenge. The program includes the development of theory, implementations in software and hardware, and explorations of potential areas for applications.

There are two projects in the Learning Systems Division—Sparse Distributed Memory (SDM) and Bayesian Learning. My talk gave an overview of the research in the SDM project.

Now in its third year, the Sparse Distributed Memory (SDM) project is investigating the theory and applications of massively parallel computing architecture, called sparse distributed memory, that will support the storage and retrieval of sensory and motor patterns characteristic of autonomous systems. The immediate objectives of the project are centered in studies of the memory itself and in the use of the memory to solve problems in speech, vision, and robotics. Investigation of methods for encoding sensory data is an important part of the research. Examples of NASA missions that may benefit from this work are Space Station, planetary rovers, and solar exploration. Sparse distributed memory offers promising technology for systems that must learn through experience and be capable of adapting to new circumstances, and for operating any large complex system requiring automatic monitoring and control. This work, which is conducted primarily within RIACS, includes collaborations with NASA codes FL and RI, Apple Computer Corporation, Hewlett-Packard Corporation, MCC, Stanford University, and other research groups to be determined.

Sparse distributed memory is a massively parallel architecture motivated by efforts to understand how the human brain works, given that the brain comprises billions of sparsely interconnected neurons, and by the desire to build machines capable of similar behavior. Sparse distributed memory is an associative memory, able to retrieve information from cues that only partially match patterns stored in the memory. It is able to store long temporal sequences derived from the behavior of a complex system, such as progressive records of the system's sensory data and correlated records of the system's motor controls. Using its records of successful behavior in the past, sparse distributed memory can be used to recognize a similar circumstance in the present and to "predict" appropriate responses. Unlike numerical and symbolic computers, sparse distributed memory is a pattern computer, designed to process very large patterns formulated as bit strings that may be thousands of bits long. Each such bit string can serve as both content and address within the memory. Our project is concerned with research into aspects of sparse distributed memory that will enable us to evaluate and someday build autonomous systems based upon sparse distributed memory.

For the coming three years we have proposed research in four general areas: theory and design of SDM architectures, representation of sensory and motor data as bit patterns suitable for SDM, organization of SDM-based autonomous systems, and exploration of important domains of application. A major objective of our research is to explore the feasibility of SDM-based systems in applications such as vision processing, language processing, robotics and motor systems, and information retrieval. Each of the named areas will involve development of theory, simulations on appropriate computers such as the CM-2, and implementations on a digital prototype of SDM.

N90-22236

Algorithms and Architectures for Robot Vision

Paul S. Schenker

Jet Propulsion Laboratory

The author has previously conducted research in vision devices, algorithms, and architectures. Most of this work has addressed problems in scene perception and object recognition in support of autonomous robotics. A number of novel algorithms have resulted, including pyramid image analysis using contrast-normalized feature extraction [1], scale-rotation-aspect invariant image analysis using polar-exponential-grid representation [2,3], and high-speed image segmentation using multi-resolution stochastic search techniques [4]. Other efforts have included development of a multi-sensor fusion approach to scene analysis, and the development of a real-time VLSI machine vision architecture [5,6].

The scope of our current work is to develop practical sensing implementations for robots operating in complex, partially unstructured environments [7,8]. A focus in this work is to develop object models and estimation techniques which are specific to requirements of robot locomotion, approach and avoidance, and grasp and manipulation. Such problems have to date received limited attention in either computer or human vision—in essence, asking not only how perception is in general modeled, but also what is the functional purpose of its underlying representations [9]. As in the past [1,2], we are drawing on ideas from both the psychological and machine vision literature. Of particular interest to us is developing 3-D shape and motion estimates for complex objects when given only partial and uncertain information and when such information is incrementally accrued over time. Our current studies consider the use of surface motion, contour, and texture information, with the longer range goal of developing a fused sensing strategy based on these sources and others.

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N90-22237

Computer Vision Techniques for Rotorcraft Low Altitude Flight

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Rotorcraft operating in high-threat environments fly close to the Earth's surface to utilize surrounding terrain, vegetation, or manmade objects to minimize the risk of being detected by an enemy. Increasing levels of concealment are achieved by adopting different tactics during low-altitude flight. Rotorcraft employ three tactics during low-altitude flight: low-level, contour, and nap-of-the-Earth (NOE). The key feature distinguishing the NOE mode from the other two modes is that the whole rotorcraft, including the main rotor, is below tree-top whenever possible. This leads to the use of lateral maneuvers for avoiding obstacles, which in fact constitutes the means for concealment. The piloting of the rotorcraft is at best a very demanding task and the pilot will need help from onboard automation tools in order to devote more time to mission-related activities. The development of an automation tool which has the potential to detect obstacles in the rotorcraft flight path, warn the crew, and interact with the guidance system to avoid detected obstacles, presents challenging problems.

This presentation describes research which applies techniques from computer vision to automation of rotorcraft navigation. The effort emphasizes the development of a methodology for detecting the ranges to obstacles in the region of interest based on the maximum utilization of passive sensors. The range map derived from the obstacle-detection approach can be used as obstacle data for the obstacle avoidance in an automatic guidance system and as advisory display to the pilot. The lack of suitable flight imagery data presents a problem in the verification of concepts for obstacle detection. This problem is being addressed by the development of an adequate flight database and by preprocessing of currently available flight imagery. The presentation concludes with some comments on future work and how research in this area relates to the guidance of other autonomous vehicles. For further details on the work reported here please refer to the following list of papers.

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Kalman Filter Based Range Estimation for Autonomous Navigation Using Imaging Sensors

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Rotorcraft operating in high-threat environments fly close to the Earth's surface to utilize surrounding terrain, vegetation, or man-made objects to minimize the risk of being detected by the enemy. The piloting of the rotorcraft is at best a very demanding task and the pilot will need help from on-board automation tools in order to devote more time to mission-related activities. The development of an automation tool, which has the potential to detect obstacles in the rotorcraft flight path, warn the crew, and interact with the guidance system to avoid detected obstacles, presents challenging problems in control, computer vision and image understanding.

The planning of rotorcraft low-altitude missions can be divided into far-field planning and near-field planning (Cheng and Sridhar, 1988). Far-field planning involves the selection of goals and a nominal trajectory between the goals. Far-field planning is based on a priori information and requires a detailed map of the local terrain. However, the database for even the best surveyed landscape will not have adequate resolution to indicate objects such as trees, buildings, wires and transmission towers. This information has to be acquired using an onboard sensor and integrated into the navigation/guidance system to modify the nominal trajectory of the rotorcraft. Initially, passive imaging sensors such as forward looking infrared (FLIR) and low-light-level-television (LLLTV) will be considered for detection to assess the limitation of passive methods. The two basic requirements for obstacle avoidance are detection and range estimation of the objects from the current rotorcraft position.

There are many approaches to the estimation of range using a sequence of images. The approach used in this analysis differs from previous methods in two significant ways: (i) we do not attempt to estimate the rotorcraft's motion from the images, and (ii) our interest lies in recursive algorithms. The rotorcraft parameters (position, translational velocity, rotational velocity and attitude) are assumed to be computed using an onboard inertial navigation system. Given a sequence of images, using image-object differential equations, a Kalman filter (Sridhar and Phatak, 1988) can be used to estimate both the relative coordinates and the Earth coordinates of objects on the ground. The Kalman filter can also be used in a predictive mode to track features in the images, leading to a significant reduction of search effort in the feature extraction step of the algorithm. The performance of three different Kalman filters for different rotorcraft maneuvers were examined in Sridhar and Phatak, 1988. This previous study did not, however, include the processing of real images. The purpose of this paper is to summarize early results obtained in extending the Kalman filter for use with actual image sequences. These tests were restricted to linear motion in order to reduce the image processing requirements. The experience gained from the application of this algorithm to real images is very valuable and is a necessary step before proceeding to the estimation of range during low-altitude curvilinear flight.

We have presented a simple recursive method to estimate range to objects using a sequence of images. The method produces good range estimates using real images in a laboratory set up and needs to be evaluated further using several different image sequences to test its robustness. The feature generation part of the algorithm requires further refinement on the strategies to limit the number of features (Sridhar and Phatak, 1989). The extension of the work reported here to curvilinear flight may require the use of the extended Kalman filter.

The research reported in this paper is part of an ongoing effort at NASA Ames to develop technologies for the automation of rotorcraft low-altitude flight. The object detection and range estimation algorithms discussed are quite general and have potential applications in robotics and autonomous navigation of vehicles. In addition to these feature-based algorithms, there are parallel efforts to investigate field-based techniques for the same range estimation applications (Menon and Sridhar, 1989; Kendall and Jacobi, 1989).

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N90-22239

Instrumentation and Robotic Image Processing Using Top-Down Model Control

Lawrence Stark, Barbara Mills, An H. Nguyen, Huy X. Ngo

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A top-down image processing scheme is described. A three-dimensional model of a robotic working environment, with robot manipulators, workpieces, cameras, and on-the-scene visual enhancements is employed to control and direct the image processing, so that rapid, robust algorithms act in an efficient manner to continually update the model. Only the model parameters are communicated, so that savings in bandwidth are achieved. This image compression by modeling is especially important for control of space telerobotics.

The background for this scheme lies in an hypothesis of human vision put forward by the senior author and colleagues almost 20 years ago—the Scanpath Theory. Evidence was obtained that repetitive sequences of saccadic eye movements, the scanpath, acted as the checking phase of visual pattern recognition. Further evidence was obtained that the scanpaths were apparently generated by a cognitive model and not directly by the visual image. This top-down theory of human vision was generalized in some sense to the 'frame' in artificial intelligence.

Another source of our concept arose from bioengineering instrumentation for measuring the pupil and eye movements with infrared video cameras and special-purpose hardware. Since the image available to the instrument camera was well-defined, a model of the view could be used to direct the image processing algorithms to particular regions of interest and to particular parameters such as the diameter of the pupil or the centroid of the corneal reflection. Thus, robust, rapid image processing could be obtained under control by the known top-down picture.

N90-22240

Computer Vision Research at Marshall Space Flight Center

Frank L. Vinz

Marshall Space Flight Center

Orbital docking, inspection, and servicing are operations which have the potential for capability enhancement as well as cost reduction for space operations by the application of computer vision technology. Research at MSFC has been a natural outgrowth of orbital docking simulations for remote manually controlled vehicles such as the Teleoperator Retrieval System and the Orbital Maneuvering Vehicle (OMV). Baseline design of the OMV dictates teleoperator control from a ground station. This necessitates a high data-rate communication network and results in several seconds of time delay. Operational costs and vehicle control difficulties could be alleviated by an autonomous or semi-autonomous control system onboard the OMV which would be based on a computer vision system having capability to recognize video images in real time. A concept under development at MSFC with these attributes is based on syntactic pattern recognition. It uses tree graphs for rapid recognition of binary images of known orbiting target vehicles. This technique and others being investigated at MSFC will be evaluated in realistic conditions by the use of MSFC orbital docking simulators.

Computer vision is also being applied at MSFC as part of the supporting development for Work Package One of Space Station Freedom. The objective of this is to automate routine tasks such as locating, fetching, storing, adjusting, or monitoring experiments, thereby relieving crewmen for more demanding tasks. This vision system would be used in conjunction with a robot arm planned for use in the laboratory module. This vision system would also relieve accuracy requirements for instrumentation of arm positioning. One approach for this has been contracted to researchers at the University of Alabama in Huntsville who are developing a real-time expert vision system. This expert system uses knowledge to achieve a high performance level at every stage of an image-to-decision paradigm.

N90-22241

Stanford/NASA-Ames Center of Excellence in Model-Based Human Performance

Brian A. Wandell

Stanford University

The human operator plays a critical role in many aeronautic and astronautic missions. The Stanford/NASA-Ames Center of Excellence in Model-Based Human Performance (COE) was initiated in 1985 to further our understanding of the performance capabilities and performance limits of the human component of aeronautic and astronautic projects. Support from the COE is devoted to those areas of experimental and theoretical work designed to summarize and explain human performance by developing computable performance models. Our ultimate goal is to make these computable models available to other scientists for use in design and evaluation of aeronautic and astronautic instrumentation.

The COE currently provides a portion of the research support of four principal investigators (Pavel, Rumelhart, Shepard, and Wandell). During the last three years more than ten graduate students and post-doctoral students have participated in the research supported by the COE. The research interests of the participating faculty members and students range across the areas of vision science, cognitive science, and neural networks.

Within vision science, two topics have received particular attention. First, we have done extensive work analyzing the human ability to recognize object color relatively independent of the spectral power distribution of the ambient lighting (color constancy). The COE has supported a number of research papers in this area, as well as the development of a substantial data base of surface reflectance functions, ambient illumination functions, and an associated software package for rendering and analyzing image data with respect to these spectral functions. The software and data base of reflectances have been distributed to laboratories around the world.

Second, the COE has supported new empirical studies on the problem of selecting colors for visual display equipment, such as CRTs, to enhance human performance in discrimination and recognition tasks. Classic color metric work, which is often used to define color specifications on visual display equipment, was performed using tasks that are inappropriate for the viewing conditions experienced by pilots. At the suggestion of our colleagues in the Vision Group at NASA-Ames, we have conducted new experiments that extend the range of measurement conditions to bring them closer into alignment with the viewing conditions encountered in flight.

N90-22242

Ames Vision Group Research Overview

Andrew B. Watson

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Computational Models of Early Vision– A major goal of our research group is to develop mathematical and computational models of early human vision. These models are valuable in the prediction of human performance, in the design of visual coding schemes and displays, and in robotic vision. To date we have models of retinal sampling, spatial processing in visual cortex, contrast sensitivity, and motion processing.

Image Coding– Based on our models of early human vision, we have developed several schemes for efficient coding and compression of monochrome and color images. These are pyramid schemes that decompose the image into features that vary in location, size, orientation, and phase. To determine the perceptual fidelity of these codes, we have developed novel human testing methods that have received considerable attention in the research community.

Motion Processing– Visual motion processing is an important capability in both man and machine. In both cases, the challenge is to convert a time-sequence of images into descriptions of image motion, and ultimately into descriptions of object motions. We have constructed models of human visual motion processing based on physiological and psychophysical data, and have tested these models through simulation and human experiments. We have also explored the application of these biological algorithms to applications in automated guidance of rotorcraft and autonomous landing of spacecraft.

Neural Networks– The human visual system comprises layers of neural networks which sample, process, code, and recognize images. Understanding these networks is a valuable means of understanding human vision and of designing autonomous vision systems. We have developed networks for inhomogeneous image sampling, for pyramid coding of images, for automatic geometrical correction of disordered samples, and for removal of motion artifacts from unstable cameras. We are collaborating with the Research Institute for Advanced Computer Science (RIACS) on networks for automatic visual pattern recognition.

Human Psychophysics– To determine fundamental aspects of human visual performance and to validate our computational models we maintain a vigorous program of psychophysical experiments on human observers. Currently this work emphasizes perception of coding artifacts, motion perception, and spatial scale of visual functions. In collaboration with Stanford, we are testing fundamental color vision capacities.

N90-22243

Pyramid Image Codes

Andrew B. Watson

Aerospace Human Factors Research Division
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All vision systems, both human and machine, transform the spatial image into a coded representation. Particular codes may be optimized for efficiency or to extract useful image features. We have explored image codes based on primary visual cortex in man and other primates. Understanding these codes will advance the art in image coding, autonomous vision, and computational human factors.

In cortex, imagery is coded by features that vary in size , orientation, and position. We have devised a mathematical model of this transformation, called the Hexagonal oriented Orthogonal quadrature Pyramid (HOP). In a pyramid code features are segregated by size into layers, with fewer features in the layers devoted to large features. Pyramid schemes provide scale invariance, and are useful for coarse-to-fine searching and for progressive transmission of images.

The HOP Pyramid is novel in three respects: 1) it uses a hexagonal pixel lattice, 2) it uses oriented features, and 3) it accurately models most of the prominent aspects of primary visual cortex. The transform uses seven basic features (kernels), which may be regarded as three oriented edges, three oriented bars, and one non-oriented "blob." Application of these kernels to non-overlapping seven-pixel neighborhoods yields six oriented, high-pass pyramid layers, and one low-pass (blob) layer. Subsequent high-pass layers are produced by recursive application of the seven kernels to each low-pass layer.

Preliminary results on use of the HOP transform for image compression show that 24-bit color images can be codes at about 1 bit/pixel with reasonable fidelity. Future work will explore related codes and more detailed comparisons to biological coding, and applications to motion processing and shape perception.

N90-22244

Intensity Dependent Spread Processor and Workstation

George Westrom

Odetics, Inc.

The Intensity Dependent Spread (IDS) is an adaptive algorithm which is modified according to the local intensity in the scene. (This results in a nonlinear process which cannot take advantage of rather nice linear transform methods.) The computation is similar to a neural net whereby intensity information is moving from each input pixel to a set of surrounding output pixels in a manner described by Cornsweet and Yellott.

A prototype of a VLSI IDS processor is being developed and implemented in a workstation environment. The workstation consists of a SUN 3/260 and a DATACUBE pipeline processor. The IDS prototype is a board set which operates in the DATA CUBE processor. The SUN 3/260 performs control, background processing, IDS simulation and image display functions.

N90-22245

Space Environment Robot Vision System

H. John Wood
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A prototype twin-camera stereo vision system for autonomous robots has been developed at Goddard Space Flight Center. Standard CCD imagers are interfaced with commercial frame buffers and direct memory access to a computer. The overlapping portions of the images are analyzed using photogrammetric techniques to obtain information about the position and orientation of objects in the scene.

The camera head consists of two 510 × 492 × 8-bit CCD cameras mounted on individually adjustable mounts. The 16-mm efl lenses are designed for minimum geometric distortion. The cameras can be rotated in the pitch, roll, and yaw (pan angle) directions with respect to their optical axes.

Calibration routines have been developed which automatically determine the lens focal lengths and pan angle between the two cameras. The calibration utilizes observations of a calibration structure with known geometry. Test results show the precision attainable is ± 0.8 mm in range at 2 m distance using a camera separation of 171 mm.

To demonstrate a task needed on Space Station Freedom, a target structure with a movable "I" beam was built. The camera head can autonomously direct actuators to "dock" the I-beam to another one so that they could be bolted together.

N90-22246

Self-Calibration of Robot-Sensor System

Pen-Shu Yeh

Goddard Space Flight Center

The process of finding the coordinate transformation between a robot and an external sensor system has been addressed. This calibration is equivalent to solving a nonlinear optimization problem for the parameters that characterize the transformation. A two-step procedure is herein proposed for solving the problem. The first step involves finding a nominal solution that is a good approximation of the final solution. A variational problem is then generated to replace the original problem in the next step. With the assumption that the variational parameters are small compared to unity, the problem that can be more readily solved with relatively small computation effort.

APPENDIX

Directory

The following is a preliminary directory of individuals involved in NASA VST. It includes participants at both Ames and Langley workshops, as well as other NASA personnel, contractors, and students.

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16. Abstract

This document attempts to provide a broad review of Vision Science and Technology within NASA. We have defined the subject, noted its applications in both NASA and the nation at large, and surveyed current NASA efforts in this area. We have noted the strengths and weaknesses of the NASA program, and have identified actions that might be taken to improve the quality and impact of the program.

This area has enormous potential. We are entering the visual age, in which visual communication is the global *lingua franca*, and robotic vision is the front end to an ever increasingly automated technology. At the intersection of computers, video, robotics, and imaging, a new science and technology is being born and it will have great consequences for NASA. To fully exploit this technological revolution, the agency should be prepared to participate actively and to assume a leadership role.

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